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Texture fading correlates with stimulus salience

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Abstract

Perceptual fading of texture targets on similarly textured backgrounds was studied in relation to stimulus salience using texture patterns defined by orientation contrast, shape contrast, and order contrast. In two independent experiments, perceptual salience of the targets was determined. In the first, the textural contrast of the stimuli was varied and their salience quantified using magnitude estimation; in the second, reaction time was measured for the same stimulus patterns. In a third experiment, stimulus fading time was determined. Whereas magnitude estimates and fading time increased, reaction time decreased with increasing textural contrast strength, the shape of the curves depending on the kind of texture pattern used. When fading time was plotted against target salience, the slopes of the regression lines for shape and order contrast were similar, while the slope for orientation contrast was steeper, indicating longer fading times at equal stimulus salience. A control experiment using short oriented bars instead of gratings revealed that this difference may be attributed to the abutting contour between the target and its surround. With this contour removed, the fading time was largely the same for all three kinds of texture patterns. In the absence of a border (no cancellation), the unconnected target areas appeared to change gradually in orientation, shape, and spatial arrangement, thereby assuming the properties of the background (substitution). © 2001 Published by Elsevier Science Ltd.

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1. Introduction

Small, dim targets presented in the peripheral visual field tend to fade from view with prolonged fixation, assuming the brightness of the surround (Troxler, 1804). This has been attributed to adaptation following continuous exposure of a patch of retina to the stimulus. The faded percept can be revived by eye movements or blinking, however, only briefly (Gerrits, Stassen, & van Erning, 1984). When the boundary is blurred, a target fades more rapidly than with sharp contours (Krauskopf, 1963). Two kinds of neural mechanisms have been proposed to account for fading: (i) local adaptation (Cibis, 1964; West, 1967; Aulhorn & Harms, 1972) and (ii) edge-activated brightness spreading (Gerrits, DeHaan, & Vendrik, 1966). This latter process is not unlike the filling in of retinal and cortical scotomas (Gerrits & Timmerman, 1969; Eysel & Schweigart, 1999). To denote the similarity, the term 'artificial scotoma' has therefore been adopted to describe the fading of large uniform targets (Gerrits & Timmerman, 1969; Ramachandran & Gregory, 1991). A comprehensive treatment of this topic has been recently published by Pessoa, Thompson, and Noë (1998).

In Gerrits and Vendrik's (1970) seminal paper, the term *filling in* was used to convey the idea of signal propagation (e.g. brightness spreading) from the *luminance*-defined edge of an enclosed region to the center. A similar spreading effect was reported by Safran and Landis (1998) for a *color*-defined edge. Here, a red disc surrounded by an unsaturated blue background disappeared from view during fixation giving way to a uniformly bluish surface. This observation cannot be explained by an afterimage, nor can it be accounted for by contrast induction from the surround (Anstis, 1984). Instead, it must rely on filling in by signal propagation from the surround.

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Spillmann and Kurtenbach (1992) demonstrated that filling in can also be induced by a *texture*-defined edge, such as the one surrounding an artificial scotoma on a background of dynamic random noise. When looking at a small gray square superimposed onto a noisy background, they observed that after a few seconds of fixation, the gray square disappeared from view to become filled in by the surrounding background texture. Moreover, after the initial stimulus was replaced by a uniform background, static dust (graininess) could be seen briefly in the area formerly occupied by the gray square. Similar results were obtained by Ramachandran and Gregory (1991; see also Ramachandran, Gregory, & Aiken; Hardage & Tyler, 1995); however, in their studies, the noise induced in the target area was described as dynamic twinkling.

Filling in can also be demonstrated on more complex, visual backgrounds such as flickering gratings or a page of print. For example, Ramachandran and Gregory (1991) found that uniformly gray patches on such backgrounds disappeared within a few seconds of fixation. Similarly, Gyoba (1997) demonstrated fading for figures composed of Chinese characters on a background of other Chinese characters differing in orientation. He attributed his results to filling in based on differences in perceptual salience.

Direct evidence for filling in came from a psychophysical experiment by Paradiso and Nakayama (1991). These authors examined the time course of filling in for a briefly exposed white disk on a black background by using various white line masks presented to the contralateral eye. They found that an interocularly presented mask interfered with the filling in process if it occurred within 100 ms after the white test disk. Although the disk was still perceived, the propagation of brightness could be stopped, preventing the disk from becoming uniformly filled in. From their data, Paradiso and Nakayama (1991) calculated the speed of brightness propagation as 110–150 deg/s. In a further study, Paradiso and Hahn (1996) modulated the luminance of a uniform disk and found that the brightness change perceived in the middle of the disk was delayed relative to the brightness change at the edge. This delay strongly suggests a propagation of the filling in process from the edge to the center.

Analogous to Paradiso and Nakayama (1991), Caputo (1998) performed a masking experiment, using textured targets on textured backgrounds of different orientation (45 deg). Strength of masking increased with increasing target size. Furthermore, a large target required a long interstimulus interval, while a small target required a short interstimulus interval, as would be expected from the assumption of a propagating filling in effect. Similarly, Motoyoshi (1999) found that a small annular mask flashed after a briefly presented texture pattern of black parallel slashes strongly suppressed the perception of texture within the mask, but not the detectability of a pop-out stimulus, e.g. a differently oriented element shown simultaneously with the texture. Speed of propagation was comparable to that reported by Paradiso and Nakayama (1991).

The question arises whether fading and filling in are unitary processes or whether one is the prerequisite for the other. An answer was given by DeWeerd, Desimone, and Ungerleider (1998), who measured the time required for fading of a gray square on a black background filled with white vertical slashes. Using various target sizes and eccentricities, they found that the longer the border, the longer the time needed for the target to disappear from view. In fact, when M-scaled, boundary length on the cortical surface predicted fading time. From their results, the authors proposed that perceptual fading occurs in two steps: a slow one, measured in seconds, during which figure–ground segregation gradually deteriorates and ultimately breaks down (cancellation); and a fast one, measured in milliseconds, during which background texture spreads from the edge and fills in the target area (substitution). Time to fading therefore predominantly reflects the first step as the second step is completed almost instantaneously.

In addition to a gray square, De Weerd et al. (1998) used a red square and found that the time to filling in was generally longer than for the gray square. They attributed this finding to the higher perceptual salience of the red square, which would delay the perceptual filling in by the background texture.

2. Aim of study

In this study, we asked whether salience would predict fading time also for various kinds of texture contrast between target and background. Furthermore, we were interested in a detailed description of the fading process when the target and the surround were not connected by a common border. To this end, we chose three different classes of texture targets with constant border lengths and location on similarly textured backgrounds. A fourth stimulus was later used as a control. Targets differed from their surrounds either in orientation, shape, or order (regularity) (Fig. 1). Specifically, we asked: does fading time correlate with the perceptual salience of the stimulus? To answer this question, we first measured perceptual *salience* using magnitude estimation and reaction time. Thereafter, we determined *fading time* for the same stimulus patterns and correlated the results with those obtained for perceptual salience.

3. Methods

3.1. General procedure

Stimuli were generated by an Apple Power Macintosh 8200 and displayed on the screen of an Apple Multiple Scan 1705 Monitor with a refresh rate of 75 Hz. Each target appeared at an eccentricity of 8 deg to the left or right of a central fixation point. To establish proper fixation, the fixation point appeared 1 s prior to the stimulus and remained present throughout the trial. The same four stimuli were used to test for perceptual salience and fading. In each experiment, the presentation of the stimuli was randomized within, as well as between, conditions. By pressing the space bar, observers themselves initiated each trial, thereby ensuring optimal attention to the task.

Four observers, aged 22–32 years and naïve to the purpose of the experiment, but highly trained in fixational tasks, participated in the experiments. They were first familiarized with the task and then seated in front of the monitor at a viewing distance of 57 cm, using a forehead-chinrest to stabilize the head. Fixation was binocular on a small cross in the center of the monitor screen, and testing was conducted in a darkened room. Practice runs served to ensure good fixation, to acquire a stable response criterion and to become familiarized with the preassigned keys on the computer keyboard. In the beginning, fixation was carefully monitored using both a flash induced foveal afterimage and an eye-movement recording device (ExpressEye, resolution 10 arcmin/ms). Since the deviations were ineligible, monitoring was limited to periodical checks. Also, observers were told to cancel trials, when they noticed that their fixation was off-center.

3.2. Stimuli

Figure and ground in the stimulus patterns were defined solely by a texture contrast between target and background. In all conditions, the region assigned to the target subtended 2×2 deg, while the background subtended 25×32 deg (entire monitor screen). There was no physical boundary between target and background, except for a spurious abutting border between the two gratings in stimulus pattern A. The textural strength in each class of stimulus pattern was systematically varied to produce stimuli of different perceptual salience.

3.2.1. Orientation contrast

The target was a squarewave grating of 0.8 c/deg surrounded by a background grating of the same spatial frequency (Fig. 1a). The mean luminance (57 cd/m^2) and Michelson contrast (0.08) were identical for target and background. Target orientation was kept constant at 0 deg (vertical orientation), while the background grating was rotated clockwise or counterclockwise resulting in seven stimuli of different orientation contrasts to the ground: 5, 10, 15, 20, 30, 45, and 60 deg. An ANOVA revealed that the results for background gratings tilted clockwise and counterclockwise did not differ; therefore, data for these two conditions were combined. When the target was rotated and the background orientation kept constant (vertical), the results were virtually the same (Fritz, 2001).

Since the target and background gratings shared a thin abutting border that appeared to have confounded the data, we later added a control stimulus consisting of short oriented bars only (Fig. 1d). This target was made up of 2×3 bars, while the surrounding background contained 40×20 bars arranged in rows and columns. Each bar was 0.3 deg in length and 0.1 deg in width. The bar luminance was 60 cd/m^2 and background luminance 52 cd/m^{2,} (Michelson contrast = 0.07). The orientation of the background was varied in seven steps as above.

3.2.2. Shape contrast

On a textured background of pseudo-randomly arranged circles ($\varnothing = 1.1$ deg), a single polygon served as a target comparable to an 'odd-one-out' stimulus (Fig. 1b). Background circles and target polygons were black outline figures on a white background. Shape contrast was defined by the number of target corners. Six

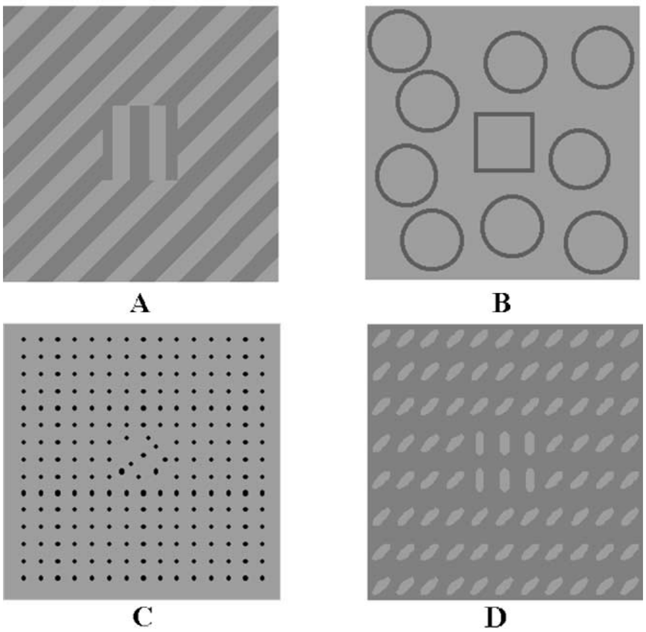


Fig. 1. Examples of the four types of texture stimuli used (not drawn to scale; the contrast of the figures is enhanced for better illustration): (a) orientation contrast defined by squarewave gratings, (b) shape contrast, (c) order (regularity) contrast and (d) orientation contrast defined by short bars. The fixation point was 8 deg left or right of the target. The background texture filled the entire monitor screen.

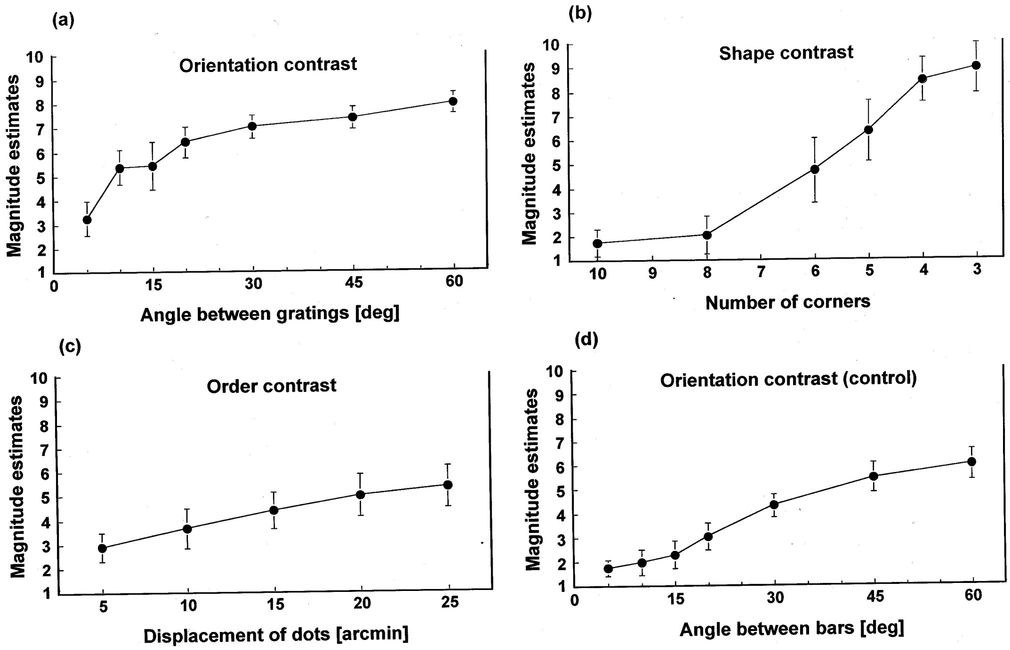


Fig. 2. Magnitude estimates plotted as a function of (a) orientation contrast (stimulus A), (b) shape contrast, (c) order contrast and orientation contrast (stimulus D). Each datum point is the average of 35 ratings from each of four observers. Vertical bars give the standard error of the mean. Note that the abscissa in (b) is reversed here as in the following two figures.

polygons were chosen: triangle, square, pentagon, hexagon, octagon, and decagon. The length of the target circumference was the same for all stimuli and was identical to that of the background circles.

3.2.3. Order contrast

On a regular array of black dots, each 12 arcmin in diameter, an irregular cluster of 3×3 dots served as a target (Fig. 1c). The order of target dots, i.e. the regularity of spacing, was systematically manipulated. While the background dots were arranged in rows and columns separated by 36 arcmin, the target dots were randomly displaced relative to the background array in four directions by 5, 10, 15, 20, or 25 arcmin, resulting in five different stimuli.

3.3. Experiment 1: Salience by magnitude estimation

3.3.1. Procedure

Perceptual salience was first measured using magnitude estimation. Stimuli were randomly presented either on the left or right side of the fixation point for 92 ms with an interval of 3 s between presentations. Following stimulus exposure, observers assigned a value between 1 and 10 to a given target in accordance with its perceived strength by pressing the corresponding key ('0' being equivalent to '10'). The short exposure duration was chosen to prevent observers from giving the same response to a given stimulus merely from memory and to discourage any eye movements.

3.3.2. Results

In Fig. 2, average magnitude estimates are plotted as a function of textural contrast as defined by the difference in orientation between target and surround gratings (a), the number of corners of the target polygons (b), the displacement of the target dots relative to the orderly array in the surround (c), and the difference in orientation between target and surround bars (d). As mentioned earlier, this last condition was a control stimulus to test for the effect of an abutting contour in condition (a). The abscissa denoting shape contrast (b) has been reversed in direction to allow for comparison with the results obtained with the other classes of texture contrast (ditto in Figs. 3 and 4).

Not surprisingly, estimates for all four targets increase with increasing texture contrast, although individual curves differ in shape as well as in their position on the ordinate. The curve for orientation contrast obtained with stimulus A (Fig. 2a) first increases steeply, but begins to flatten out already at an angular difference of 20 deg, whereas the curve for shape contrast (Fig. 2b) initially runs parallel to the abscissa, before it increases linearly from eight to four target corners and then asymptotes also. Both curves reach values near the top of the magnitude estimation scale. In comparison, the curve for order contrast (Fig. 2c) is almost linear with a rather shallow slope reaching a magnitude estimate of 5, while the control curve obtained with stimulus D (Fig. 2d) shows a sigmoidal increase levelling off at an estimate of 6.

3.4. Experiment 2: Salience by reaction time

3.4.1. Procedure

Perceptual salience was next measured using a reaction time paradigm. Targets were presented until the observer pressed one of two keys to indicate the side of target presentation. Stimuli were followed by a textured mask of randomly oriented short black lines with a duration of 500 ms to eliminate any afterimage; the interstimulus interval was 2.5 s. Observers were in-

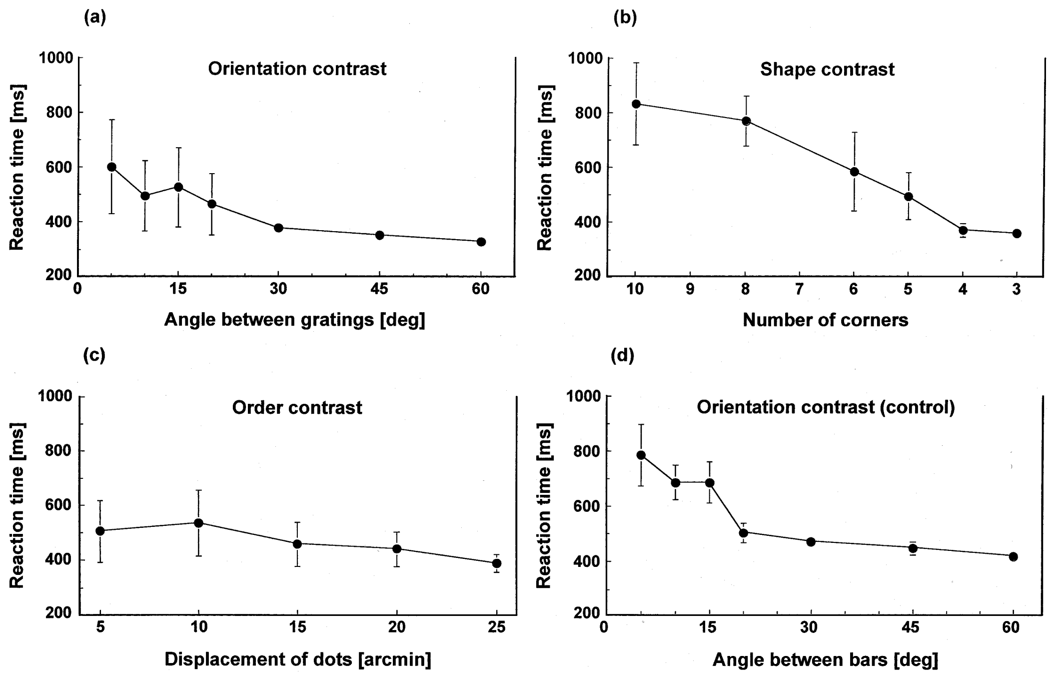


Fig. 3. Reaction time for the correct detection of the target plotted as a function of (a) orientation contrast (stimulus A), (b) shape contrast, (c) order contrast and orientation contrast (stimulus D). Each datum point is the average of 25 measurements in each of four observers. Vertical bars give the standard error of the mean.

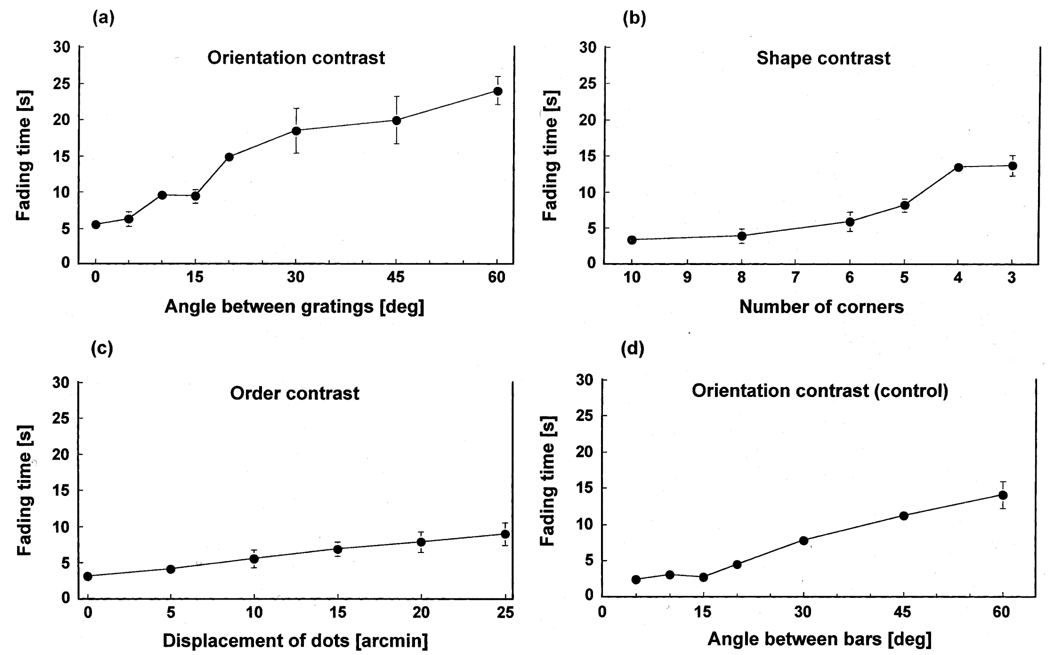


Fig. 4. Fading time plotted as a function of (a) orientation contrast (stimulus A), (b) shape contrast, (c) order contrast and (d) orientation contrast (stimulus D). Each datum point is the average of 10 measurements in each of four observers. For orientation and order contrast, measurements at zero angle and zero displacement represent a phase-offset only. Vertical bars give the standard error of the mean.

structed to respond promptly and correctly. False responses (< 1%) were negligible and were excluded from the analysis.

3.4.2. Results

Average reaction times are plotted again as a function of textural contrast (Fig. 3a–d). In general, reaction times for all target classes decrease with increasing texture contrast consistent with the increase in salience by magnitude estimation (Fig. 2). As in Experiment 1, we obtained different shapes and ordinate values for the individual curves representing the different classes of texture contrast. The curve for shape contrast (Fig. 3b) exhibits the steepest slope across the largest range of reaction times, whereas the two curves for orientation contrast (Fig. 3a and d) and that for order contrast (Fig. 3c) decrease more slowly and, in the case of order contrast, again almost linearly. Note that reaction times for orientation contrast due to stimulus D (Fig. 3d) were always higher than those for orientation contrast due to stimulus A (Fig. 3a) and thus salience was lower.

3.5. Experiment 3: Time to fade

3.5.1. Procedure

In this experiment, fading time was determined for each target. Stimuli were initiated by pressing the space bar. Observers were instructed to maintain fixation at the central cross while attending to the peripheral target stimulus, and to press a key when the target became invisible for the first time (it typically re-appeared with eye movements and blinking). The time to fade from stimulus onset to response (i.e. *fading time*) was recorded.

3.5.2. Results

Fig. 4a–d shows fading time as a function of textural contrast (as defined before). For all types of stimuli, fading time increases with increasing texture contrast. As in the preceding experiments, the shapes and slopes of the functions differ across texture classes. While the curve for orientation contrast based on stimulus A (Fig. 3a) proceeds from 5 to almost 25 s, the control curve for orientation contrast based on stimulus D (Fig. 3d) ascends more slowly and reaches a maximum fading time of only 15 s. The two remaining curves for shape contrast (Fig. 3b) and order contrast (Fig. 3c) run low and level off at 15 and 10 s, respectively.

To compare fading times across the four different target-surround textures, we plotted the time required for fading (ordinate) against perceptual salience (abscissa) as a common measure. Fig. 5a combines the results for fading time (from Experiment 3) with those of magnitude estimation (from Experiment 1). Analogously, Fig. 5b combines results for fading with those of reaction time (from Experiment 2).

The various symbols in Fig. 5 represent the different types of texture contrast used. In both figures, there is a positive correlation between fading time and perceptual salience, as defined by increasing magnitude estimation on the one hand and decreasing reaction time on the other. However, for both types of correlations, data for the different texture stimuli do not fall onto the same regression line. Regression equations are given in Table 1.

Whereas the regression lines for shape contrast (squares), order contrast (triangles) and orientation contrast obtained with stimulus D (crosses) have fairly similar slopes and run close to each other, the slope of the regression line for orientation contrast obtained with stimulus A (circles) evidently is much steeper. This relationship is reflected in the ratios between the slopes of the regression lines for both measures of salience when the slope for shape contrast is arbitrarily set to 1. For magnitude estimation (Fig. 5a), we obtain ratios of the slopes for shape, order, and orientation contrast (stimuli D and A) of 1:1.30:1.82:2.67; similarly, for reaction time (Fig. 5b), the ratios are 1:1.35:1.23:2.32. Thus, targets of equal salience representing shape, order and orientation contrast (stimulus D) fade approximately at the same time, whereas targets for orientation contrast (stimulus A) require fading times twice as long.

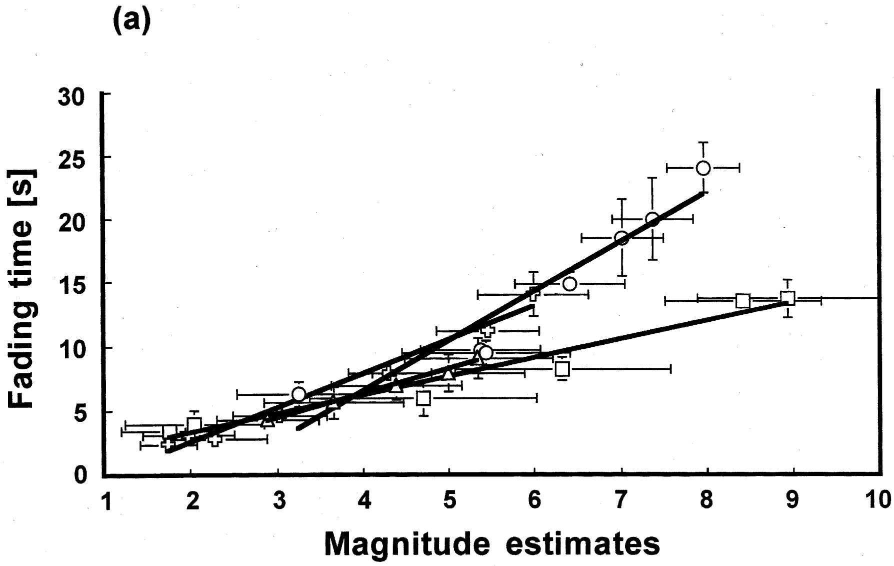
4. Discussion

4.1. Role of texture in fading

De Weerd et al. (1998) proposed that the time to disappearance of a target on a textured background correlated with the boundary length of the target representation on the surface of the cortex. The target in these experiments was uniformly gray or red, and the background consisted of short, vertical slashes. We tested whether and to what extent perceptual salience of the target would predict fading and filling-in.

Using different classes of texture targets on similarly textured backgrounds, we found that fading time increased systematically with an increase in perceptual salience, even if the circumference of the targets was kept constant. The finding that the regression lines for each texture stimulus have their own slopes (Fig. 5) and that the ratios between slopes agree well for magnitude estimation and reaction time suggests that for each texture contrast, perceptual salience represents a stimulus-specific predictor for fading time.

Order contrast (stimulus C) produced the shortest fading times, followed by shape contrast (stimulus B), orientation contrast (stimulus D) and, with a wide margin, orientation contrast (stimulus A). While the first three targets had no contiguous border with the background, the latter shared an abutting edge with the



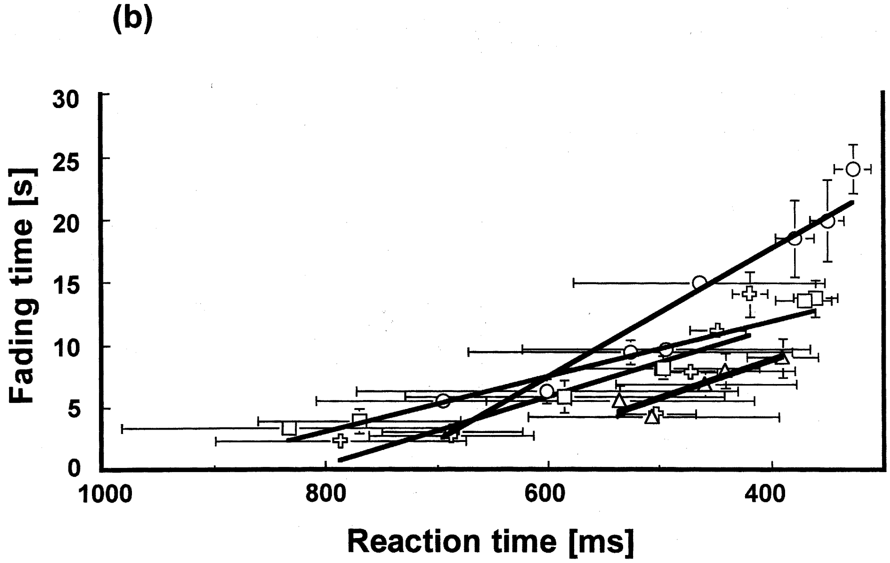


Fig. 5. Fading times plotted as a function of perceptual salience measured with (a) magnitude estimation and (b) reaction time. Data from Fig. 4 are combined with data from Fig. 2 (top) and 3 (bottom). Circles represent orientation contrast (stimulus A), squares shape contrast (stimulus B), triangles order contrast (stimulus C), and crosses orientation contrast (stimulus D). Horizontal and vertical bars represent the standard error of the mean. Note that the abscissa in (b) is reversed to reflect increasing perceptual salience.

surrounding grating. Therefore, the steeper slope obtained with this pattern (in Fig. 5) is attributed to the extra time required to break down the apparent boundary. Perceived stratification in depth between target and background may have delayed fading further because of the enhanced figure–ground segregation. This interpretation is consistent with the assumption of figure–ground segregation (V1) and abutting contours (V2) originating prior to textural fading and filling in (V3) (DeWeerd, Gattass, Desimone, & Ungerleider, 1995).

There are parallels between our results and texture-contrast studies in the literature. For example, Nothdurft (1993) found that salience for a short bar popping out from a similarly textured background increased with increasing difference in orientation. This finding agrees with our results in Figs. 2 and 3 and is consistent with the correlation between fading time and orientation contrast in Fig. 4. Caputo (1998) also described a masking effect that became weaker with an increase in difference between the orientations of the target and the background textures. From these results, he proposed that spreading should occur in a direction predominantly collinear with the orientation of the texture elements.

4.2. Qualitative description of texture fading

Even with careful observation, it was difficult to describe in detail the process by which a textured stimulus (figure) becomes embedded in a similarly textured background. What we can state is that for grating orientation contrast (stimulus A), the target became less distinct just before it was perceptually replaced by the background texture. Specifically, the target first appeared to lose its abutting contour with the background followed by a disintegration into oriented patches just before the background texture took over the target area. No gradual rotation of the target towards the orientation of the background was perceived.

In comparison, in the case of shape contrast (stimulus B), the target polygons became less conspicuous by gradually changing their perceived shape towards a circle. Similarly, in the case of order contrast (stimulus C), the cluster of jumbled target dots appeared to gradually shift their positions to accommodate the orderliness of the surrounding background array. The same kind of change was true for orientation contrast in the control stimulus (stimulus D), where the short target bars seemed to approach the orientation of the background bars.

4.3. Neural hypothesis

In a study in the behaving monkey, DeWeerd et al. (1995) found a possible neural correlate of fading by recording from neurons in cortical area V3. A gray square on a slashed background was used as described above. With the uniform test field located entirely inside a given receptive field, the neuron responded with a brief on-transient followed by a steep fall-off and a subsequent slow increase of the discharge rate. This 'climbing activity' may reflect a decrease of inhibition due to adaptation, resulting in the recovery of excitation and producing perceptual filling in from the surround. The experimental curve reached the level of the control curve (obtained with a uniform background, but no test field present) at about the same time when human observers reported fading and filling in (7–11 s). The authors suggested that one event was the neural correlate of the other and proposed that during fixation, the perception of the border between figure and ground had first to break down before the target could fade.

This proposal holds true for the abutting contour in stimulus A, which deteriorated before the grating stripes snapped into alignment with the orientation of the background. The other three targets (stimuli B, C, D) were spatially noncontiguous with the surround, and thus, there was (a gradual) substitution without border cancellation. In each case, the higher the salience of a stimulus, the stronger was its resistance towards fading and filling in. Whether the lowering and ultimate breakdown of figure–ground segregation in textured stimuli is accomplished by a suppression from the surround (inhibition), or a top-down signal intended to make the stimulus region appear uniform with the background, is open to conjecture.

Our finding (Fig. 4a and d) that fading time increases with increasing orientation contrast is consistent with neurophysiological results in the cat and monkey showing that the neuronal response to an oriented line (grating) becomes stronger with increasing difference between target and background (Knierim & van Essen, 1992; Kastner, Nothdurft, & Pigarev, 1999). Furthermore, horizontal connections in the visual cortex have been shown to occur most frequently between neurons with similar orientation preferences (Gilbert & Wiesel, 1989; Schmidt, Goebel, Loewel, & Singer, 1997), which is consistent with a shorter fading time for near-collinear stimuli. Long-range interactions from outside the classical receptive field (Kapadia, Ito, Gilbert, & Westheimer, 1995; Spillmann & Werner, 1996) may thus be a candidate mechanism responsible for textural fading.

Table 1
Regression lines for the texture contrast patterns used

	Regression line
Fading time vs. magnitude estimation	
Orientation contrast (stimulus A)	$y = -9.1 + 3.88x$ ($R^2 = 0.90$)
Shape contrast	$y = 0.31 + 1.45x$ ($R^2 = 0.95$)
Order contrast	$y = -1.33 + 1.88x$ ($R^2 = 0.99$)
Orientation contrast (stimulus D)	$y = -2.83 + 2.64x$ ($R^2 = 0.97$)
Fading time vs. reaction time	
Orientation contrast (stimulus A)	$y = 38.0 - 0.051x$ ($R^2 = 0.91$)
Shape contrast	$y = 20.6 - 0.022x$ ($R^2 = 0.91$)
Order contrast	$y = 20.6 - 0.030x$ ($R^2 = 0.81$)
Orientation contrast (stimulus D)	$y = 22.1 - 0.027x$ ($R^2 = 0.74$)

5. Conclusion

The questions raised in Section 1 may be answered as follows. This study shows that physical strength of texture contrast correlates with fading time in accordance with perceptual salience of the stimulus: the higher the salience, the longer the fading time. However, different slopes of correlation (in Fig. 5) suggest that each type of texture-contrast possesses its own relationship between fading time and perceptual salience. For example, in our experiment, shape (stimulus B), order (C) and orientation contrast (D) required much shorter fading times at equal salience than the orientation contrast (stimulus A), which was characterized by an abutting border.

While our observations with stimulus A are consistent with the hypotheses by DeWeerd et al. (1995) and Caputo (1998) that fading and filling in of a uniform (or textured) patch on a texture-defined background occur in two consecutive steps, border cancellation and substitution from the surround, the results obtained with three of our stimuli favor a more gradual change of the target in direction of the surround. Furthermore, from the finding that in the absence of eye movements a stimulus with high visibility (salience) remains visible longer than a weak stimulus, one may speculate that pop-out and fading represent the beginning and end of the same perceptual continuum. Related mechanisms may thus be involved in both mediating pop-out (figure–ground segregation) and fading and filling in (failure to segregate).

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